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A REVIEW OF BIOMEDICAL ASPECTS OF CB MASKS AND THEIR RELATIONSHIP TO MILITARY PERFORMANCE

U S ARMY RESEARCH INSTITUTE OF ENVIRONMENTAL MEDICINE

Natick, Massachusetts

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by

Stephen R. Muza, Ph.D.

October 1986

US ARMY RESEARCH INSTITUTE OF ENVIRONMENTAL MEDICINE

NATICK, MASSACHUSETTS 01760-5007

FORWARD

This report was prepared at the request of NATO Research Study Group - 7. As part of the Study Group's comprehensive report on the Biomedical Aspects of Military Clothing, the author was responsible for preparing Chapter 11: "Biomedical Aspects of NBC Masks and their Relation to Military Performance". It appeared worthwhile to place this review in a form that is more readily available then the NATO report. This Technical Report represents an adapted version of the original chapter prepared for the RSG - 7 report.

TABLE OF CONTENTS

ABSTRACT

This review describes the most important factors affecting military work performance while wearing a CB mask: 1) the additional inspiratory and expiratory breathing resistance; 2) increased external dead space; 3) thermal stress of the mask and hood; 4) restriction of functional vision; 5) hinderance of speech transmission and reception; 6) weight, size and pressure on the face by the CB mask; 7) claustrophobic reactions and 8) sleep loss and lack of nutrient intake due to long-term wear. In assessing the biomedical aspects of these factors, rather than making comparisons between specific models of CB masks the review addresses these factors as they apply to CB masks in general.

INTRODUCTION

Soldiers are provided with individual protective garments to guard them from nuclear, biological and chemical (NBC) contamination. A key item of these protective garments is the chemical and biological protective mask (CB mask). CB masks can provide respiratory protection against radioactive particles and field concentrations of all known chemical and biological agents in both vapor and aerosol form.

The first employment of CB masks in warfare was during World War I (17). Initially, German soldiers were equipped with the "face mask of the Gent zone." This mask consisted of a cotton dressing sewn to a cloth the size of a handkerchief; the cotton dressing was soaked in alkaline sodium thiosulfate prior to use and the mask had to be kept moist during use. After the first major attack with Chlorine gas at Ypres (Ieper), Belgium in April 1915, the German Army issued the forerunner of the modern gas mask. It consisted of an oiled leather, bag-shaped mask with a filter which screwed to the body of the mask. Straps held the mask against the face. The British developed and issued their Small Box Respirator, which consisted of a rubber facepiece holding two glass eyepieces and a breathing tube which was connected to a filter-box. The French developed their own filter-box respirator called the Tissot. The U.S Army was mainly equipped with the British Small Box Respirator but, owing to its high resistance to breathing, the U.S. modified the French mask, and late in the war issued the lower resistance American Tissot mask.

Concurrent with the employment of the CB mask, the physiological and psychological burdens of CB mask wear began to emerge. The most important parameters affecting military work performance with a CB mask include: 1) the additional inspiratory and/or expiratory breathing resistance; 2) increased external dead space; 3) thermal stress of the mask and hood; 4) restriction of functional vision; 5) hindrance of speech transmission and reception; 6) weight, bulk and pressure on the face and head of the respirator and its straps; 7) claustrophobic reactions and 8) sleep loss and lack of water and nutrient intake associated with long-term wear. This report's objective is to present a review of these factors, and how they can degrade the soldier's ability to perform military tasks.

1. ADDED RESISTANCE TO BREATHING

Resistance Standards for CB Masks. The healthy adult has an average airway resistance of 0.8 $cmH_2O \cdot l^{-1} \cdot s^{-1}$. By contrast, the typical modern CB mask produces about a four-fold increase in the resistance to breathing. Although an early recognized limitation of the CB mask was its inspiratory and expiratory resistance, the development of standards for acceptable levels of breathing resistance of CB masks did not occur until World War II. Several studies by Silverman et al. (57,58) investigated the effects of breathing against added resistance while working at various rates on a cycle ergometer. Healthy male subjects exercised for 15 minute periods at work rates ranging from 68 to 180 watt (W) with added inspiratory resistances ranging from 0.4 to 7.5 $cm\ H_2O \cdot l^{-1} \cdot s^{-1}$. (CB mask airflow resistance is typically measured at an airflow of 85 $l \cdot min^{-1}$. However, many of the resistances reported in this text were measured between 30 to 100 $l \cdot min^{-1}$ airflows). Increases in the resistance to breathing resulted in decreased submaximal oxygen uptake and minute ventilation at work rates above 135 W. Most subjects were able to tolerate the increased resistance provided the total respiratory work required to breathe through a mask (usually calculated by integration of the instantaneous product of pressure and flow) did not exceed 0.41 W at the low workloads and 2.2 W at the high workloads. These data have provided the basis for most modern military CB mask design criteria and certification tests.

In 1960, Cooper (10) suggested standards of resistance which he expressed as the rate of respiratory work done on a breathing apparatus per minute ventilation. The maximum respiratory work rate done on a mask expressed in $kgm \cdot min^{-1}$ was arbitrarily set at one- fourth of the minute ventilation expressed in $l \cdot min^{-1}$ (e.g., if the minute ventilation is 40 $l \cdot min^{-1}$, then the maximum rate of respiratory work done on a mask should not exceed 10 $kgm \cdot min^{-1}$ (1.6 W)). Since Silverman et al. (57) had suggested lower levels of respiratory work, Cooper acknowledged that this standard may represent an excessive resistance and that the ideal mask may have a resistance one-half of this standard. However, Cooper believed that with training in breathing against resistance and improved physical condition, subjects could tolerate this level of respiratory work. Thirteen years later, Bentley et al. (6) re-evaluated tolerance to added resistance to breathing in 158 mine rescue workers during exercise. The exercise consisted of a 30-minute walk on a treadmill with the work rate altered between subjects to obtain a wide range of minute ventilations. The added inspiratory resistance ranged from 2.4 to 21.0 cm $H_2O \cdot l^{-1} \cdot s^{-1}$. After completion of the exercise, each subject selected one of four statements which most closely described his sensation of the effect of the resistance on his breathing. The results indicated that both the peak inspiratory pressure and the inspiratory work rate per liter of inspired air were closely correlated with the sensation of dyspnea (shortness of breath). From these data, Bentley et al. (6) formulated a standard for acceptable resistance such that 90% of the population tested would not experience dyspnea. They determined that the level of external respiratory work done on a mask should not exceed 1.7 $J \cdot l^{-1}$ of inspired air or under steady flow conditions, the pressure drop across the inspiratory valve and filter should not exceed 17.0 cm H_2O. This level of tolerable external respiratory work is below those suggested by Cooper (10), but above those derived by Silverman et al. (57).

Given the pressure-flow characteristics of several different CB masks (U.S. M17A1, M25, XM40; British S6 and Netherlands C-3) and applying Bentley et al. (6) results one can predict that discomfort in breathing would be experienced by 10% of the wearers at minute ventilations ranging from 55 to 89 $l \cdot min^{-1}$. These minute ventilation levels are commonly attained during moderate to heavy intensity exercise and may represent the threshold above which the widespread development of dyspnea may impair soldier work performance.

Respiratory Responses to Loaded Breathing. The physiological mechanism(s) by which added resistance to breathing impairs work performance is potentially complex. Several studies (9,18,27) have investigated the effects of added resistance applied to inspiration and/or expiration during exercise at various intensities. With increasing added resistance to breathing, minute ventilation and endurance time decreased at each level of exercise. The reduction in ventilation was directly proportional to the increase in resistance. Hermansen et al. (27) noted that ventilatory rates were lower with the CB mask on and rose to only 30 $breaths \cdot min^{-1}$ during exercise. Maximal oxygen uptake ($\dot{V}O_2$ max) was reduced, but the relationship between oxygen uptake and submaximal workload (> 75 percent of $\dot{V}O_2$ max) was not altered. However, there was no clear evidence that an additional shift to anaerobic metabolism occurred. When breathing through added resistance, the relative hypoventilation resulted in an increase of alveolar carbon dioxide, which may impair the capacity for work (via a mixed metabolic and respiratory acidosis). Cerretelli et al. (9) also observed that at the highest levels of exercise the work could no longer be tolerated when the intrathoracic pressure difference between inspiration and expiration exceeded 100 cm H_2O. They speculated that when intrathoracic pressure swings approach this level, some protective mechanism intervenes to limit the respiratory work.

Demedts and Anthonisen (18) observed that at each level of added resistance, maximum exercise ventilation was about 70 percent of the 15 sec maximum voluntary ventilation measured with that resistance. Second, in four of the five subjects they examined, an important relationship was observed between these individuals' ventilatory response to CO_2 and the degree of their respiratory effort while breathing against added loads. When breathing was opposed by added resistance, subjects with low CO_2 sensitivity minimized their ventilatory effort and let their alveolar CO_2 rise; in contrast, those subjects who were most sensitive to CO_2 increased their respiratory work and maintained alveolar CO_2 near normal. Consequently, by increasing their minute ventilation, the latter subjects' exercise intensity and duration were more limited by the added resistance. The authors concluded that the exercise limitation imposed by added resistance to breathing depends both on the ventilatory limitations produced by the resistance and on the CO_2 responsiveness of the individual.

Several investigators (14,29) have shown that this limitation of ventilation during exercise results from attempts to minimize the total respiratory work by reducing the expiratory duration (T_E) in order to prolong the inspiratory duration (T_I) of each breath. Since the CB mask produces its greatest resistance to breathing during inspiration, this strategy reduces inspiratory work while letting expiratory work increase slightly. Johnson and Berlin (29) demonstrated in 10 subjects that a minimum T_E of 0.66 s corresponded to the voluntary termination of exercise. However, Stemler and Craig (62) observed a variable T_E at the termination of exercise. They suggested that the minimal T_E attained is more a function of expiratory resistance than a general limitation on expiratory performance. Expiratory resistance of CB masks can be increased by hood designs which increase protection against agent penetration by incorporating a "neck dam". Still, when wearing a CB mask, minute ventilation can increase in response to the metabolic demands of the exercise until a minimum T_E is reached. Thereafter, minute ventilation falls below the metabolic needs of the individual and impairs continued exercise performance.

When breathing is opposed by resistance loads, the ventilatory responses are regulated by the combined actions of mechanical load compensation intrinsic to the respiratory muscles and neural load compensation which are extrinsic to the muscles (3). In conscious humans, the ventilatory response to resistive loading is also modulated by neural responses mediated by conscious perception of the added load (3,65). The CB mask opposes breathing by applying a non-linear, phasic, flow-resistive load. It is further defined as a passive load since the respiratory muscles must develop forces to overcome the load. Axen et al. (3) analyzed ventilatory responses to 10 consecutively loaded (range 10-45 cm $H_2O \cdot l^{-1} \cdot s^{-1}$) inspirations. The first breath response to the added resistance was an increased duty cycle (T_I/T_T) due to a lengthened T_I, and a decreased mean inspiratory flow (V_T/T_I) caused by the reduction of V_T. Consequently, minute ventilation was reduced. During subsequent breaths, minute ventilation progressively increased toward control levels due principally to augmentation of mean inspiratory flow (increased V_T), suggesting an increase in neural drive to the respiratory muscles. These ventilatory adjustments to added resistance probably represent the combined action of intrinsic muscle properties, extrinsic neural load compensation, and consciously mediated responses as well as the chemical drive for ventilation.

Minute ventilation is dependent upon the transformation of central respiratory drive into muscle force which acts upon the chest wall. The chest wall is divided into two parts, the rib cage and abdomen. Three principal muscle groups act upon the rib cage and abdomen to displace them: the intercostal muscles, the diaphragm and the abdominal muscles. A recent study (40) reported that the rib cage (intercostal muscles) contribution to tidal volume increased significantly, from 68% during quiet breathing to 78% when inspiring through added resistance. The authors suggested that there was a greater recruitment of the rib cage inspiratory muscles than the diaphragm during resistive loading, although intrinsic properties of the chest wall musculature may also have contributed. Furthermore, the authors observed an increased mean expiratory flow rate following the loading inspiration. This enhanced emptying was attributed to a reduction in expiratory-braking by the rib cage inspiratory muscles. These observations suggest that during mechanical loading of inspiration the distribution of respiratory motor activity is altered.

A potential consequence of prolonged work while wearing a CB mask is respiratory muscle fatigue. During exercise with no opposition to breathing, ventilatory muscle endurance does not appear to constitute a limitation to exercise performance (7). However, the work of breathing increases as the resistance increases. The greater the fraction of the maximum inspiratory muscle force developed to breathe across a resistance, the greater the energy demands of the muscle. Several studies have found that development of diaphragm fatigue was dependent upon both the relative tension developed (53) and the duration of the contraction (5). More recently, McCool et al. (38) determined that the velocity of muscle shortening, as characterized by inspiratory flow, also influences the endurance of the inspiratory muscles.

Although it has been speculated that respiratory muscle fatigue is a limiting factor of work performance when wearing CB masks, this relationship has not been demonstrated.

As stated earlier, in conscious humans the ventilatory response to mechanical loading is also modulated by neural responses mediated through conscious perception of the added load (3). Using the psychophysical technique of scaling, it is possible to assess subjects' performance in judging the magnitude of respiratory sensations (47). Results of several studies suggest that signals related to respiratory muscle force generation (2) and motor command (8) contribute to the sensation of respiratory loads.

Perceptual performance during a scaling task is very reproducible within a given subject, but varies greatly between different subjects (32). Little is known concerning the important question of whether or not an individual's sensitivity to respiratory sensations influences how he regulates ventilation when breathing is opposed. Two studies (23,46) have demonstrated a relationship between subjects' sensitivity to respiratory sensations and ventilatory load compensation. Their results suggest that subjects who have a greater sensitivity in scaling added inspiratory loads are better able to preserve their ventilation when unexpectedly confronted with an added load. The wide range of perceptual performance observed in the healthy adult population may account for the reported variability between subjects in the degree of discomfort felt and the tolerance to exercise under similar conditions of physical stress while breathing through a CB mask.

Cardiovascular Responses. Several studies have evaluated the cardiovascular responses to loaded breathing. Hermansen et al. (27) reported that average heart rates during submaximal exercise were higher when wearing the M19 CB mask, but were similar at maximum exercise intensity to those obtained without added resistance to breathing. Conversely, Van Huss et al. (63) reported reduced exercise heart rates with CB mask wear. Furthermore, the exercise heart rates were inversely related to the magnitude of the added resistance to breathing. Lerman et al. (35) observed similar heart rate responses during short duration, high intensity exhausting exercise. As the magnitude of the inspiratory resistance increased from 0.3 to 4.6 cm $H_2O \cdot l^{-1} \cdot s^{-1}$, the heart rates at the end of each run decreased from 190 $\pm$ 2 to 185 $\pm$ 2 beats $\cdot$ min^{-1}. Other studies (45,51) have reported no differences in exercise heart rates associated with CB mask wear. The physiological mechanism(s) responsible for the heart rate alterations is not clear. Possibly, the larger intrathoracic pressures occurring with CB mask wear enhance venous return and therefore stroke volume resulting in lower heart rate via the baroreflex.

Blood pressure responses during exercise appears to be unaltered by CB usage. Two studies (35,51) reported no significant differences in systolic blood pressure measurements during short-term fatiguing exercise. However, in a third study (61) a 24 percent increase in recovery systolic blood pressure was reported when wearing CB mask during a Harvard Step Test. This result suggests increased cardiovascular stress during exercise with CB mask usage.

Exercise Performance Limitations. Many studies have investigated the exercise performance decrement that can be attributed to CB mask wear. With tasks that demand a high percent of maximal aerobic power, performance seems to be dependent on breathing resistance (30). Cummings et al. (15) reported that wearing a CB mask increased the time to accomplish a one-half mile run by 11%. Lotens (37) found a 16% performance decrement during 400 m and 3 km runs while wearing the C-3 respirator and he notes that similar results were obtained during British studies of their S-6 respirator. Several studies (12,35) have demonstrated that any amount of added resistance to breathing causes a decrease in exercise endurance and performance. Most studies have tested work performance of men wearing masks using both fixed task-variable rate and fixed rate-variable time end points. A different approach to evaluating work performance is the use of perceived exertion or sense of effort to set and adjust exercise intensity.

Pandolf and Cain (49) demonstrated that when subjects maintain exercise at a constant sense of effort, they decrease the intensity of the exercise over time. The relationship between exercise intensity and exercise duration is known as a constant effort function. Recently, we studied constant effort dynamic cycle exercise (for 20 minutes) in order to learn whether the constant-effort functions were affected by added inspiratory resistance (5.8 cm $H_2O \cdot l^{-1} \cdot s^{-1}$). Preliminary results demonstrate that with minimal inspiratory resistance (1.0 cm $H_2O \cdot l^{-1} \cdot s^{-1}$) the constant-effort functions declined approximately 20% during the initial eight minutes of exercise and then remained relatively constant. With the added inspiratory resistance, the constant-effort functions followed a similar pattern for the initial eight minutes but then continued to decline throughout the exercise period reaching a power output that was approximately 30% below the starting level. The subjects also performed maximal exercise tests with the same minimal and increased inspiratory resistance levels. Although increased inspiratory resistance caused a significant reduction of peak minute ventilation, the maximal oxygen uptakes and peak power output levels were not altered. These data suggest that while this level of inspiratory resistance may not diminish achievement of maximal power output and aerobic capabilities for short durations (>10 minutes), it does enhance the subjects' perceived sense of effort during prolonged exercise. Consequently, while wearing CB masks, individuals engaged in military tasks requiring high levels of physical exertion for sustained durations are subject to performance degradation. This is consistent with the observations of Lotens (36), who observed that performance is dependent on the magnitude of the breathing resistance as well as the duration of the task.

2. EXTERNAL DEAD SPACE

Effective gas exchange in the lungs requires an adequate amount of fresh air entering the alveoli with each breath. Consequently, each tidal volume is composed of an anatomical dead space volume (the air in the airways at the end of expiration) and an alveolar volume. In a normal adult male the anatomical dead space has an internal volume of about 150 ml. The alveolar volume is increased or decreased depending on the metabolic needs of the subject. The external dead space is an extension of a subject's anatomic dead space. It is the volume of expired air contained within the mask which during the next inspiration must be moved into the alveoli before any fresh, filtered environmental gas can enter. When a soldier dons a CB mask, he artificially increases his dead space volume. If the soldier does not increase his tidal volume, then the volume of fresh air entering the alveoli will decrease for a given breath. Bartlett et al. (4) found that minute ventilation increased when the external dead space exceeded 50 ml. They also observed a nearly linear relationship between external dead space volume and ventilation during submaximal exercise. When the external dead space is increased (e.g., by wearing a CB mask) the soldier initially inspires a larger fraction of carbon dioxide enriched gas. As the alveolar CO_2 increases, so does the arterial partial pressure of CO_2 (P_aCO_2). The stimulus to increase minute ventilation in response to added external dead space is this elevation in arterial CO_2 termed "hypercapnic drive". The increased P_aCO_2 stimulates the peripheral and central chemoreceptors, which increase ventilatory drive via the respiratory control centers in the brainstem. Since the ventilatory sensitivity to CO_2 varies greatly between individuals, a given volume of external dead space can produce a wide range of ventilatory responses.

Modern CB masks are designed to minimize the size of the external dead space. However, dead spaces between 300-500 ml are common to CB masks. Furthermore, a poor seal of the mask's nose cup or internal partitions with the wearer's face can result in internal mask leaks, which may increase the volume of the external dead space. Craig et al. (13) have shown that an increase in inhaled CO_2 is not well tolerated when combined with increased resistance. Since the effect of increased dead space is increased minute ventilation, tasks requiring aerobic performance can be degraded by the sustained increase of ventilation and the additional work of breathing. Furthermore, specialized tasks which require precise control over breathing motions (i.e., sharpshooting, etc.) can be hindered by the responses to external dead space.

3. THERMAL STRESS OF THE CB MASK AND HOOD

The CB mask will have to be worn in a variety of environmental extremes. In warm environments, the addition of a CB mask and its associated hood to the NBC protective overgarment will increase the heat stress level imposed on the soldier. This increased heat stress can limit the soldier's performance of military tasks by increasing physiological and psychological strain.

Physical Effects. The transfer of heat from the body via the head is simply a function of the surface area available. Since the head constitutes less than 10% of the body surface area, the proportion of the total body heat loss by the head is generally relatively small. However, when any clothing, and in particular chemical protective overgarments, are worn the relative contribution of the head to total body heat loss increases as the other areas of the body are covered. Consequently, wearing a CB mask and hood over the head can seriously reduce the already limited heat loss capability of the body. In a study done by the U.S. Army (19) with an air motion of 0.3 $m \cdot s^{-1}$, the insulating air layer around a bare head was reported as 0.64 clo units. The evaporative moisture permeability (i_m) was 0.62 yielding a permeability index ratio (i_m/clo) value of 0.97; i.e., sweat evaporation cooling from the bare head is only 3 percent less than the maximum evaporative cooling capacity of the environment. When the standard U.S. M-1 helmet was worn, the i_m/clo value dropped to 0.43 indicating greater than a fifty percent reduction in heat transfer from the head.

Subsequently an evaluation of the U.S. M17 mask, alone and with the M6 protective hood, was conducted (22) to discriminate the heat stress effects of a protective hood from the heat stress effects of the CB mask. In still air, the standard U.S. helmet and M17 CB mask on a sweating sectional manikin head yielded an i_m/clo value of 0.13; with the addition of the impermeable M6 hood, the permeability index ratio decreased to 0.02 i_m/clo. Assuming that a soldier is wearing a helmet, donning a CB mask without a hood can reduce heat transfer from the head by approximately 70 percent and adding the hood can make the total decrease in heat transfer greater than 90 percent. Furthermore, the M6 hood also covers the shoulders and seals the opening at the jacket's collar, thus reducing evaporative heat transfer from the torso area by about 25%. If the body is already having difficulty in meeting its requirements for heat loss; i.e. if protective garments are being worn, this loss of heat transfer from the head and torso could result in significantly increased core temperature and decreased work performance as a result of the increased body heat storage.

A soldier wearing a CB mask in direct sunlight may gain heat in the area of his face by the mask's "green house effect". Belard (personal communication) has shown that radiant energy entering through the mask's lenses can cause the temperature within the mask to rise several degrees. CB masks with large lenses or transparent facepieces collect more radiant energy. However, the ventilatory induced air motion within the mask attenuates this green house effect. Heat gain via this pathway maybe a problem, or atleast a nuisance, during tasks requiring minimal movement and subsequently low ventilatory rate (e.g., manning an observation post, etc).

Physiological Effects. Several studies have attempted to evaluate the effect of CB mask wear on the physiological responses during exercise in the heat. Robinson and Gerking (52) studied, in two heat acclimated subjects, the effects of CB masks on sweat rate, heart rate and body temperature in both hot/wet (T_a = 30.5°C, T_{dp} = 27.7°C) and hot/dry (T_a = 45°C, T_{dp} = 26°C) environments. In both environments the subjects wore jungle fatigues, and exercised for two hours (~350 W). Wearing a CB mask and impermeable hood elevated sweat rate by about 28% above the no mask and hood controls in the hot/wet and by about 16% in the hot/dry environment. Mean skin temperature was increased, but core temperature was not further elevated when the mask and hood were worn. Finally, heart rate tended to be higher with the mask on.

Similar results were obtained in a British study (39) in which the heat stress of an S6 respirator was evaluated in four heat acclimated subjects in a test environment of T_a = 34.0°C and T_{dp} = 25.5°C. The exercise consisted of 120 minutes of bench stepping, which yielded a work rate of ~230-350 watt. The subjects were tested with and without the S6 CB mask wearing an Army tropical khaki uniform or the same uniform with the UK No. 1, Mk 1, NBC protective overgarment and neoprene gloves. Final exercise sweating rates and heart rates were significantly elevated when wearing the CB mask compared to the no mask condition. However, the CB mask had a significant effect on final exercise rectal temperature only when the CB protective overgarment was worn. Finally, with both uniforms, wearing the mask elevated skin temperature. The authors also demonstrated that as the total sweat loss increased, that portion attributed to wearing the mask decreased. However, as rectal temperature increased, the effect on rectal temperature attributed to the mask significantly increased. Finally, the authors concluded that the elevated heart rate measured during mask wear was due to the mask and could not be attributed to an elevation in core temperature.

James et al. (28) recently evaluated the effects of two industrial respirators on physiological responses to work in the heat. Five unacclimatized subjects wearing trousers and long-sleeved shirts performed one hour treadmill exercise tests at two work rates (58 and 116 W) and in two environmental conditions (T_a = 25°C, T_{dp} = 14°C and T_a = 43.3°C and T_{dp} = 14°C). These four tests were conducted with the subjects wearing either a half face or full face air-purifying respirator or a Collins large mouthpiece and nose clip ("no mask" condition). No hood was worn with any of the masks. When compared to the "no mask" condition, both masks significantly elevated heart rate, by about 9 percent. Core (oral) temperature was significantly elevated (0.33°C) during the 116 watt exercise while wearing the full facepiece respirator compared to the no mask condition. Likewise, the full facepiece respirator increased minute ventilation about 18 percent compared to the no mask control. The authors attributed this minute ventilation elevation to the large dead space of the full facepiece mask. Neither mask had any effect on whole body sweat rate or metabolic rate in either the comfortable or the hot dry environment which should not be surprising in view of the clothing worn and the low ventilatory demand of the work. However, the authors concluded that the greater dead space volume and surface area covered by the full facepiece mask is associated with a greater physiological strain than when the half-mask type of respirator is used. Belard (personal communication) has observed that sweating under the CB mask and hood causes an uncomfortable accumulation of liquid which soaks the chin. Also, it has been reported that sweat may penetrate the filter elements in CB masks which contain the filters within the mask facepiece (e.g., U.S. M17). This can cause increased inspiratory resistance and degradate the filters protective function.

Psychological Effects. Aside from the actual physiological strain imposed by wearing CB masks in warm environments, there exists the psychological acceptability of a CB mask in these environments. Factors such as the dry bulb temperature and dew point of the air inside the CB mask, and facial skin wettedness, affect the temperature and comfort sensations for the whole body. In a recent study by Gwosdow et al. (24), six subjects wearing ventilated masks during rest and exercise in a wide range of environmental conditions were asked to rate their whole body thermal sensation and perception of breathing effort. Increasing the dry bulb or dew point temperatures in the mask decreased whole body thermal acceptability. The whole body thermal sensations were directly correlated with upper lip skin temperature. Moreover, the subjects perceived breathing to be more difficult with increasing intra-mask temperature and humidity. CB mask acceptability and the capacity to perform essential military tasks may be severely degraded by the interaction of soldiers' psychological acceptability of the CB mask and the increased physiological strain due to CB mask wear. In military vehicles containing microclimate cooling systems, consideration should be given to the temperature and humidity control of the cooling air ventilating the facepiece.

4. VISUAL LIMITATIONS

The successful employment of surveillance and weapon systems on a modern battlefield, requires minimal interference with a soldier's functional vision. Wearing a CB mask can significantly degrade a soldier's vision, resulting in substandard performance of military tasks (11,41). Degradation of functional vision can be the result of several factors, including: 1) visual field restrictions; 2) reduced dynamic visual acuity; 3) dark adaptation; and 4) altered space perception. Also, it should be noted that, under certain circumstances, CB mask wear can contribute to the development of conjunctivitis; masks which are ventilated by a blower can produce a flow of dry air across the eye which could cause irritation of the surface of the eyeball.

Visual Field Restrictions. Standard clinical procedures employing Projection Perimeter apparatus have been used to obtain visual field measurements. Usually, the visual field measurements made when wearing a CB mask are compared to the "no mask" (unrestricted) measurements. A CB mask reduces the wearer's visual field; the magnitude of the reduction is dependent upon the design of the facepiece and its fit on the subject's face. Three basic lens designs are usually used in CB masks. These include: 1) two separate binocular lenses; 2) a single piece windshield lens; and 3) a single full facepiece (panoramic) lens. Masks using the two binocular lenses (U.S. M-17, British S6) generally demonstrate the greatest decrement in visual field. This style of lens particularly restricts the inferior medial and inferior oblique portions of the visual field (21,64). All styles of lenses tend to restrict the inferior visual field. This common observation can probably be attributed to CB masks incorporating a voicemitter assembly and/or exhalation valve on the exterior of the oral-nasal portion of the facepiece; this exterior assembly blocks the wearer's inferior visual field.

A second factor which can affect the wearer's visual field is proper fit of the mask on the user. For example, if the surface of the lens is positioned far ahead of the eyes, then the visual field is further restricted. An additional factor which may affect the wearer's visual field is the wear of corrective lens. Most CB masks provide for the use of spectacle inserts which provide eyeglass wearers with the necessary refractive power to maintain normal vision when wearing a CB mask. The potential exists for users of spectacle inserts to experience further degradation of their visual field due to the interference with peripheral vision normally attributed to corrective lens wear. Finally, the visual field can be further reduced by fogging of the mask's lenses or accumulation of opaque material (dirt, frost) on the lenses.

Alignment of the eye with weapon and surveillance systems optical sights can be hindered by the size and shape of a CB mask. This could decrease the effectiveness of these systems. However, performance of certain tasks may be enhanced by CB mask wear. The narrower field of view may eliminate distractions and help the soldier concentrate on his task. Hand-eye coordination tasks may be degraded by CB mask. However, a recent study by Johnson <u>et al.</u> (31) showed that wearing a CB mask and hood (M17A1) did not impair the manual dexterity of soldiers performing the O'Connor Five Finger Dexterity Test or the Purdue Pegboard Assembly Test. Since both of these tests only require a small field of vision, they are probably not good measures of manual dexterity tasks which occur over a large visual field.

<u>Dynamic Visual Acuity.</u> CB mask wear has been shown to reduce the dynamic visual acuity of the wearer (64). The typical test of dynamic visual acuity requires the subject to track a target at a constant rate across the visual field, while the target angular size and direction of travel are randomly varied. In a study done by the U.S. Army (64), where wearing a CB mask the target

angular size had to be increased by 7-38% over "the no mask" condition to achieve a 95% detection criterion. These results indicate that CB mask wear interferes with the wearer's ability to detect and then track a rapidly moving target. This loss of performance may be attributed to the scattering of light by the mask lens. This degradation of dynamic visual acuity can hinder a soldier's ability to detect moving targets, or the ability of an operator of a moving combat vehicle (air or ground) to avoid obstacles.

Many military tasks require the detection of visual events or signals occurring anywhere in the visual field. Kobrick and Sutton (34) developed a laboratory device for measuring the voluntary response time to such visual stimuli. The task required the subject to monitor stimulus lights distributed about the visual field and to depress a handheld push-button switch whenever the onset of a signal light was detected. Average response time was tabulated as a function of the stimuli location within the visual field. In a subsequent study, Kobrick and Sleeper (33) compared the effects of wearing NBC protective clothing (U.S. Army MOPP IV) on the ability to detect visual signals throughout the visual field. Tests were conducted while the subjects wore the U.S. Army battledress uniform or the NBC protective ensemble including the M17A1 mask for a continuous 8-hour period.

With no CB mask on, significant increases in response times for visual signal detection occurred with peripheral displacement of the target. These impairments became substantially greater when the subjects were wearing the CB mask while encapsulated in CB protective garments. With no mask, the mean response times also increased with visual stimulus locations in the superior and inferior visual field areas, and were shortest with targets along the horizontal axis of view, again, wearing the CB mask and protective overgarment significantly increased these response times. There was no progressive cumulative effect of wearing the protective overgarment and CB mask over the daily 8-hour testing session. These results indicate that wearing a CB mask and protective overgarment seriously limits functional vision. Furthermore, this limitation occurs with the donning of the protective ensemble and remains undiminished for at least eight hours.

Dark Adaptation. The transmission of light through the lenses of CB masks is reduced by the material comprising those lenses. This may interfere with the soldier's ability to detect targets which have low illumination at night. In a test (64) of the effect of CB mask wear on visual sensitivity following 40 minutes of dark adaptation, mask wear degraded visual sensitivity approximately 1 log unit. Hence, the apparent brightness and information content of images transmitted through the CB mask is reduced. The reduced transmission of light through the lens of CB masks could also reduce the definition of images by shifting the operation of the visual system from the area of central vision (fovea centralis) to the periphery of the retina. The fovea centralis consists only of specialized nerve endings called cones. The cones are responsible for the high optical efficiency of the fovea centralis. Although the cones do adapt to the dark, their threshold shift is not nearly as extensive as that of the rods (20). Consequently, when wearing a CB mask at night, vision may become totally dependent on the activity of rods, and thus will be degraded.

Altered Space Perception. The proper perception of space and distance is a basic requirement for the successful performance of tasks requiring good depth discrimination. Proper space perception when wearing a CB mask depends upon minimizing the prismatic power of the lens material. Prismatic power alters the normal convergence of the incident light thereby changing the convergence demand of the oculomotor system (64). Excessive prismatic power could upset the balance of the accomodative and convergence components of the eye, resulting in degradation of functional vision and development of ocular distress (eye strain). The utilization of spectacle inserts by soldiers requiring corrective lenses can also alter space perception. In many CB masks, spectacle inserts can become loose, thus displacing the alignment of the lenses with the eyes. This may cause altered space perception, eye strain and optical distortions which could further reduce the visual field and visual acuity. Consequently, the ability to perform military tasks can be greatly degraded if not made impossible to accomplish.

5. SPEECH TRANSMISSION AND RECEPTION

A key element in the successful accomplishment of military tasks is clear verbal communications. The physical transmission and reception of audio signals are significantly degraded by wear of a CB mask and hood. This hindrance of audible signals by the CB mask and hood is primarily the result of three factors: 1) degradation of speech transmission; 2) attenuation of sound reception; and 3) increased ambient noise.

Speech Transmission. Most CB masks are equipped with a voicemitter assembly which permits the transmission of speech by the wearer of the mask. Typically, the voicemitter is located in the mask's nose cup area in front of the soldier's mouth. In some CB masks, a smaller auxiliary voicemitter is located on a side of the mask beside the nose cup. This additional voicemitter permits the normal use of telephone style communications handsets. As sound passes through the voicemitter, the transmission quality is degraded and the signal volume is reduced. In a 1967 study of speech amplifier systems for protective CB masks, Abbagnaro et al. (1) found that the M17 mask alters normal speech response by producing a roll-off of the speech energy above 1000 Hz. This roll-off at high frequencies gives the speaker's voice a bassy, muffled quality and reduces the speech intelligibility by hindering transmission of consonant sounds.

Sound Reception. Sound reception is not impeded by the wear of a CB mask which does not cover the ears. However, the hood which is normally worn in conjunction with a CB mask can hinder sound reception. The degree to which sound reception is degraded is probably dependent upon the hood material, the fit of the hood over the head, and the tightness of the hood's seal to the other garments. The U.S. M6 impermeable hood, which is coated with butyl rubber, muffles sound. On the other hand, the British NBC smock and attached hood are made of permeable materials. This style of hood has been shown to produce negligible attenuation of sound below 2 kHz (54).

Numerous tests of CB mask wear on the performance of individual combat skills have demonstrated large degradation of verbal communication task performance (11,16,41). In a stressful combat environment with both the speakers and listeners wearing CB masks, it is very likely that voice commands will be severely hindered or completely impossible. The use of hand signals will be essential. However, previously discussed restrictions on functional vision may also degrade this form of communication.

Ambient Noise. Although wearing a CB mask and hood muffles sound reception, it simultaneously increases the level of background sound or noise heard. The primary source of increased noise is the soldier and his garments and equipment. When wearing a CB mask and hood, the soldier is more likely to hear sounds associated with his breathing and with movement of his clothing. This increased level of ambient noise can reduce the soldier's ability to detect external sounds and their source. Consequently, performance of surveillance-type tasks which depend upon auditory cues may be degraded.

Operators of air and ground combat vehicles wear noise attenuating communications headsets. The headset provides the soldier communications and hearing protection from the operational environment. A British study (54) evaluated the effect of wearing the NBC hood under an AFV Crewman's Helmet on noise attenuation. The results indicated that wearing the hood under the helmet increased the level of noise reaching the soldier's ear. Thus, the hearing protection afforded by the helmet was decreased when wearing the CB hood. Similarily, recent U.S. Army studies (44,48) found that the wear of several models of CB masks under the SPH-4 aviator helmet significantly reduced the noise attenuation function of the helmet at all frequencies evaluated. It was determined that the mask's straps passing near the ears created a leakage path for the noise. This loss of protection can aggravate hearing loss among crew members and adversely affect communications. Future CB mask and hood designs should be integrated with the combat crewman's helmet and headset to maintain adequate hearing protection and communications.

6. CB MASK FORCES ON THE HEAD

Wearing a CB mask requires it to be supported by the head. Furthermore, the efficiency of the CB mask in preventing agent penetration of the respiratory tract is dependent upon establishing an adequate facial seal. Force is transmitted to the face and scalp in the process of attaining a reliable seal. The combination of forces applied to the head, face and scalp by a respirator certainly affects the soldier's personal comfort and the mask's acceptability. Moreover, these forces may have numerous physiological effects including fatigue of head and neck muscles and restriction of cutaneous and facial muscle blood flow.

Generally, CB masks weigh less than 1 kg. However, due to their displacement far anterior of the Occipito-Atlantal articulation, the weight of a CB mask could produce forces causing flexion of the head. In order to maintain a heads-up posture, a soldier has to overcome the force of the mask by increasing the activity of muscles which produce extension of the head (i.e., the Rectus capitis posticus major and minor, the Superior oblique, the Complexus, Splenius and the upper fibers of the Trapezius). Consequently, the potential exists for accelerated development of fatigue in these muscles. Even in the absence of muscle fatigue, the constant load on this muscle group could result in the development of pain, tenderness, a stiff neck, backache or headache. These symptoms have been reported by soldiers during wear of CB masks (16,25).

When a CB mask is properly worn, pressure is applied against the skin of the face and scalp by the peripheral edge of the mask and by the straps and buckles which secure it to the head. Under these pressure points, irritation and abrasion of the skin has been reported (16,25,59). Belard (personal communication) reported that in French tests contact pain appeared within 2-5 hours under the forehead and temples. The extent of damage done to the skin is related to the magnitude of the force applied, the hardness (durometer) of the mask's periphery and the surface area covered by the seal or straps. Damage to the skin can be minimized by reducing the force against the skin (60), constructing the mask's periphery of lower durometer material and increasing the seal's surface area to better distribute the forces (21). The restriction of cutaneous and muscle blood flow and drainage of the lymphatic vessels is affected by the same mechanical factors listed above. Restriction of lymph drainage from the scalp results in the formation of edema, which has been observed during wear of CB masks (16). Development of skin abrasions and edema could result in the soldier experiencing discomfort and irritability of sufficient magnitude to degrade the successful accomplishment of military tasks. Stemler and Craig (62) found that wearing a US M9 CB mask with the lenses, voicemitter, valves and filter, removed still resulted in a significant reduction of exercise duration. These results indicate that the forces applied to the head by the CB mask can degrade the performance of military tasks requiring aerobic activity.

7. PSYCHOLOGICAL PROBLEMS

In a recent article (42) Morgan reviewed several of the psychological problems associated with the wearing of protective respirators. Among these problems are CB mask discomfort, claustrophobia and development of anxiety and hyperventilation.

Mask discomfort depends on a variety of factors. A number of these have already been reviewed (pressure points of the head and face, sensations of breathing difficulty, temperature and humidity inside the mask, limits on vision, speech and hearing). Additionally, there is the individual's perception of the degree of stress each of these factors imparts. Recently, Morgan and Raven (43) tested the hypothesis that an individual's likelihood of experiencing distress when exercising while wearing a mask, could be predicted from their level of trait anxiety. They tested 45 male subjects by first administering Spielberger's trait anxiety scale and then giving three submaximal exercise tests while the subjects wore a self-contained breathing apparatus with an inspiratory resistance of 6.07 cm $H_2O \cdot l^{-1} \cdot s^{-1}$. Spielberger's model of trait anxiety predicts that high scoring individuals would be more likely to experience anxiety attacks when performing physically hard work while breathing through a mask. Morgan and Raven (43) predicted that subjects with trait anxiety scores one standard deviation or greater above the group mean would experience respiratory distress during the exercise while wearing the breathing apparatus. The results confirmed their hypothesis. Based on the trait anxiety scores, the "hit" rate for predicting distress was 83 percent and their accuracy for predicting no respiratory distress was 97 percent. These results demonstrated that trait anxiety was effective in predicting the development of respiratory distress during exercise while wearing a breathing apparatus.

A recent series of studies (50) by the U.S. Army, assessed the capability of soldiers to conduct sustained military field operations while wearing full chemical clothing ensemble. The 81 soldiers were administered a battery of psychological tests (including subjective symptoms and a coping strategy inventory) prior to and after the field operations. Soldiers who failed to complete the 72-hour operation were classified as casualties. The single symptom which maximized the difference between the survivors and casualties was that the latter quit because it "hurts to breathe". Consequently, the perception of respiratory discomfort could compromise the performance of military operations.

The manifestations of an anxiety attack while wearing a CB mask include the psychophysiological consequences of hyperventilation, which can lead to decrements in military task performance (42). Hyperventilation can produce symptoms including dyspnea, tachycardia, dizziness, blurred vision, paresthesia, trembling and tetany; full-blown attacks can result in convulsions and disturbances of consciousness. Psychomotor performance is impaired by hyperventilation; the degree of psychomotor deterioration appears to be inversely related to the alveolar P_{CO_2}. In most individuals, hyperventilation does not manifest all these symptoms. However, some individuals are apparently more sensitive to the effects of hyperventilation. Individuals possessing this sensitivity are characterized as susceptible to the hyperventilation syndrome (42); such individuals may be more prone to experience respiratory distress while wearing a CB mask and performing physically demanding military tasks.

8. COMPLICATIONS OF LONG-TERM WEAR

The potential exists for the employment of chemical warfare agents on the modern battlefield for prolonged periods of time. Accordingly, soldiers may have to remain in their individual protective equipment for extended periods. This requirement places on the soldier's protective equipment the need to accommodate such normally routine, physiological functions as eating, drinking, elimination of body waste and sleep. Of these functions, the CB mask interferes with the soldier's ability to drink fluids, eat food and sleep.

The latest CB masks (U.S. M17A1, XM40, British S10) incorporate a drinking system which permits the consumption of beverages from the soldier's canteen, but with difficulty. The principal problem associated with their use is the manipulation of the system while wearing the bulky protective gloves. Under the stressful conditions of combat, the soldier may forgo drinking because of the perceived increased effort to accomplish the task. A recent study by the U.S. Army (Armstrong, personal communication) showed that soldiers wearing the M17A1 CB mask significantly reduced their water consumption during prolonged walking compared to the no CB mask condition. Consequently, the soldier may become hypohydrated. Hypohydration will reduce physiological work performance in soldiers in comfortable environments. Since the soldier may be under a thermal stress imposed by the wear of an NBC overgarment, hypohydration would substantially increase his physiological strain and reduce military work performance (56).

Current CB masks do not permit the soldier to take in nutrients other than what may be contained in beverages and difficulties with cleaning the drinking attachment suggest it should be limited to ingestion of water. During extended periods of encapsulation, lack of nourishment could realistically cause a degradation in performance. Henschel et al. (26) evaluated the effect of starvation on exercise performance in 12 men. They observed a significant decrease (~32%) in the endurance of the men to perform high intensity work after only the second day of starvation. The combination of starvation and CB mask and protective garment wear may degrade the ability of soldiers to perform such high intensity tasks as combat vehicle rearming, rapid runaway repair and sustained artillery fire. Providing the soldier with the capability to eat while wearing a CB mask may help maintain his physical strength and will certainly improve morale. The result could be more effective execution of military tasks.

Soldiers encapsulated in protective garments for extended periods would, when sleep was possible, have to do so in their protective equipment. The wear of the CB mask can interfere with the soldier's ability to sleep (16). There are primarily four factors, previously discussed, which affect the soldier's ability to sleep while wearing a CB mask: resistance to breathing, external dead space, forces on the head and psychological stress. Soldiers sleeping while wearing CB masks have reported waking and feeling short of breath. In some cases, the soldier may partially or completely occlude the inlet valve of the mask by rolling onto the CB mask during sleep. It is also possible that, with the lower minute ventilation during sleep, the ratio of total dead space to tidal volume may increase. This would cause a lower alveolar ventilation rate and a subsequent increase in arterial carbon dioxide; this hypercapnia could wake the soldier. The pressure of the CB mask on the face and development of pressure points as the soldier's head changes position during sleep could produce irritation and pain sufficient to wake the wearer. Finally, some soldiers may be fearful of sleeping in a contaminated environment because they believe that the mask's seal may leak as they move during sleep. No matter what the specific cause of the sleep loss, sustained sleep deprivation can seriously degrade effective performance of military tasks (25). Sleep loss can also impair a soldier's ability to thermoregulate (55). Since soldiers wearing CB masks would likely be wearing NBC protective garments, the combination of sleep loss and increased heat stress will likely result in elevated physiological strain and reduced exercise performance. Sleep loss can be expected while wearing CB masks, and this factor should be considered during the planning of military operations.

SUMMARY

The function of a nuclear, biological and chemical protective mask (CB mask) is to protect the respiratory system from nuclear, biological and chemical warfare agents and, in concert with a hood, protect the face, eyes and head from percutaneous agents and skin contamination. While accomplishing these functions, the CB mask and hood frequently impose a variety of physiological as well as psychological burdens on its user. Foremost of these burdens is the added resistance to breathing. Although modern CB masks have relatively low levels of air flow resistance, several studies have shown that mask wear will reduce exercise endurance and intensity. This reduction in exercise performance may be manifested by both physiological as well as psychological responses. CB mask wear increases the work load on the respiratory muscles and consequently the potential for development of muscle fatigue. The perception of effort during exercise while wearing a CB mask is increased and unpleasant respiratory sensations, such as breathlessness, may develop which can cause a soldier to stop performing work. Wear of the CB mask and hood may also increase the heat stress imposed on the soldier which can degrade performance of military tasks by increasing their physiological and psychological strain.

The face and head contain the principal sensory (eyes, ears, nose) and communication (mouth) structures of the body. Since the CB mask and hood encapsulates these structures in order to protect them from contamination, impairment of sensory reception and vocal communication may occur. The degree of degradation observed is dependent upon the specific task and the conditions under which it is accomplished. For example, tasks requiring a large visual field are degraded by mask wear whereas tasks utilizing a small visual field might not be affected. Also, due to the rich sensory innervation of the face and head, almost everyone who wears a CB mask experiences some discomfort.

Long-term wear of the CB mask and hood can accentuate the distress experienced by a soldier by interfering with basic facial hygiene, eating and sleeping. The result could be lower morale, increased physiological and psychological strain and loss of military effectiveness.

REFERENCES

1. Abbagnaro, L.A., A.J. Rosenheck and A.L. DiMattia. Development of a speech amplifier system for protective masks. Tech. rpt. 1089-CLD-1776, U.S. Army Edgewood Arsenal, Maryland, Dec. 1967.

2. Altose, M., A. Dimarco, S. Gottfried and K. Strohl. The sensation of respiratory muscle force. Am. Rev. Respir. Dis. 126:807-811, 1982.

3. Axen, K., S. Haas, F. Haas, D. Gaudino and A. Haas. Ventilatory adjustments during sustained mechanical loading in conscious humans. J. Appl. Physiol. 55:1211-1218, 1983.

4. Barlett, H.L., J.L. Hodgson and J. Kollias. Effect of respiratory valve dead space on pulmonary ventilation at rest and during exercise. Med. Sci. Sports 4: 132-137, 1972.

5. Bellemare, F. and A. Grassino. Evaluation of human diaphragm fatigue. J. Appl. Physiol. 53:1196-1206, 1982.

6. Bentley, R.A., O.G. Griffen, R.G. Love, D.C. F. Muir and K.F. Sweetland. Acceptable levels for breathing resistance of respiratory apparatus. Arch. Environ. Health 27:273-280, 1973.

7. Bye, P.T.P., G.A. Farkas and C.H. Roussos. Respiratory factors limiting exercise. Ann. Rev. Physiol. 45:439-51, 1983.

8. Campbell, E.J.M., S.C. Gandivia, K.J. Killian, C.K. Mahutte and J.R.A. Rigg. Changes in the perception of inspiratory resistive loads during partial curarization. J. Physiol. (London) 309:93-100, 1980.

9. Cerretelli, P., S. Rajinder and L. Farhi. Effect of increased airway resistance on ventilation and gas exchange during exercise. J. Appl. Physiol. 27:597-600, 1969.

10. Cooper, E.A. Suggested methods of testing and standards of resistance for respiratory protective devices. J. Appl. Physiol. 15:1053-1061, 1960.

11. Cox, T.J. and A.R. Jeffers. Ground crew chemical defense equipment performance task-time degradation test. Tech. Rpt. 81-5003, U.S. Air Force Aeronautical Systems Division, Dayton, Ohio, May 1981.

12. Craig, F.N., H.L. Froehlich and W.V. Blevins. Inspiratory resistance as a limiting factor in exhausting work. Tech. Rpt. 4230, U.S. Army Edgewood Arsenal, Maryland, Oct. 1968.

13. Craig, F.N., W.V. Blevins and E.G. Cummings. Exhausting work limited by external resistance and inhalation of carbon dioxide. J. Appl. Physiol. 29:847-851, 1970.

14. Craig, F.N., W.V. Blevin and H.L. Froehlich. Training to improve endurance in exhausting work of men wearing protective masks: A review of some preliminary experiments. Tech. Rpt. 4535, U.S. Army Edgewood Arsenal, Maryland, July 1971.

15. Cummings, E.G., W.V. Blevins, C.M. Greenland and F N. Craig. Effects of protective masks on soldier's ability to run a half mile. Tech. Rpt. 2254, U.S. Army Edgewood Arsenal, Maryland, 1958.

16. Cummings, E.G., J. Marrero and E. Bird. Seventy-two hour outdoor wearing trial of individual CBR protective clothing with M17 mask and E33 hood under simulated combat conditions. Tech. Rpt. 3097, U.S. Army Chemical Research and Development Laboratories, Maryland, Sep. 1967.

17. Davis, R.H. Breathing in Irrespirable Atmospheres. The Saint Catherine Press LTD., London, 1947.

18. Demedts M. and N.R. Anthonisen. Effects of increased external airway resistance during steady-state exercise. J. Appl. Physiol. 35:361-366, 1973.

19. Fonseca, G.F. Heat transfer properties of military protective head gear. Tech. Rpt. 74-29, U.S. Army Research Institute of Environmental Medicine, Natick, MA, Jan. 1974.

20. Geldard, F.A. The Human Senses, 2nd Edition. John Wiley and Sons, Inc., New York, pp 28-32, 48-51, 1[illegible]2.

21. Goldberg, M.N., D.H. Mangelsdorf, R.E. Jones, T.P. Crooks and F.W. Mazy. Individual respiratory protection against chemical and biological agents. Contract DA 18-035-AMC-286(A), U.S. Army Edgewood Arsenal, Maryland, Oct. 1966.

22. Goldman, R.F. Biophysical evaluation of relative heat stress of four chemical protective mask/hood systems. Rpt. C-028/MT21-84, Multi-Tech Corp., Natick, MA, Dec. 1984.

23. Gottfried, S.B., M.D. Altose, S.G. Kelsen and N.S. Cherniack. Perception of changes in airflow resistance in obstructive pulmonary disorders. Am. Rev. Respir. Dis. 124:566-570, 1981.

24. Gwosdow, A.R., R. Nielsen, L.E. Berglund and A.B. Dubois. Comfort and acceptability of respiratory protection devices as affected by temperature and humidity. In Proc.Am. Ind. Hyg. Assoc., Dallas, 1986, pp 41-42.

25. Haslam, D.R. Sustained operations with special reference to operational clothing and combate equipment. 13th Commonwealth Defense Conference on Operation Clothing and Combat Equipment, Malaysia, 1981.

26. Henschel, A., H.L. Taylor and A. Keys. Performance capacity in acute starvation with hard work. J. Appl. Physiol. 6:624-633, 1954.

27. Hermansen L., Z. Vokac and P. Lereim. Respiratory and circulatory response to added air flow resistance during exercise. Ergonomics 15:15-24, 1972.

28. James, R., F. Dukes-Dobos and R. Smith. Effects of respirators under heat/work conditions. Am. Ind. Hyg. Assoc. J. 45:399-404, 1984.

29. Johnson, A.T. and E.G. Cummings. Mask design considerations. Am. Ind. Hyg. Assoc. J. 36:220-228, 1975.

30. Johnson, A.T. and H.M. Berlin. Exhalation time characterizing exhaustion while wearing respiratory protective masks. Am. Ind. Hy. Assoc. J. 35:463-467, 1974.

31. Johnson, R.F. and L.A. Sleeper. Effects of chemical protective handwear and headgear on manual dexterity. In Proceedings of the Human Factors Society, Santa Monica, 1986, pp 994-997.

32. Killian, K.J., C.K. Mahutte and E.J M. Campbell. Magnitude scaling of externally added loads to breathing. Am. Rev. Respir. Dis. 123:12-15, 1981.

33. Kobrick, J.L. and L.A. Sleeper. Effect of wearing chemical protective clothing in the heat on signal detection over the visual field. Aviat. Space Environ. Med. 57:144-148, 1986.

34. Kobrick, J.L. and W.R. Sutton. Device for measuring voluntary response time to peripherally placed stimuli. Percep. Mot. Skills. 30:255-258, 1970.

35. Lerman, Y., A. Shefer, Y. Epstein and G. Keren. External inspiratory resistance of protective respiratory devices: effects of physical performance and respiratory function. J. Am. Ind. Med. 4:733-740, 1983.

36. Lotens, W.A. Clothing design and its relation to military performance. Institute for Perception, National Defense Research Organization TNO, Rpt. IZF-1982-34, Nov. 1982.

37. Lotens, W.A. Physiological Strain: Clothing, physical load and military performance. In: Aspects medicaus et biophysiques des vetements de protection. Centre de Recherches du Service de Sante des Armees, Lyon, pp 268-279, 1983.

38. McCool, F.D., D.R. McCann, D.E. Leith and F.G. Hoppin, Jr. Pressure-flow effects on endurance of inspiratory muscles. J. Appl. Physiol. 60:299-304, 1986.

39. Martin, H. deV. and S. Callaway. An evaluation of the heat stress of a protective face mask. Ergonomics 17:221-231, 1974.

40. Mengeot, P.M., J.H.T. Bates and J.G. Martin. Effect of mechanical loading on displacements of chest wall during breathing in humans. J. Appl. Physiol. 58:477-484, 1985.

41. Montague, W.E., R.D. Bakner and A.H. McClure. The effects of wearing the CBR protective mask upon the performance of selected individual combat skills. Tech. Rpt. 57, The George Washington University Human Resources Research Office, Washington, D.C., 1959.

42. Morgan, W.P. Psychological problems associated with the wearing of industrial respirators: A review. Am. Ind. Hyg. Assoc. J. 44:671-676, 1983.

43. Morgan, W.P. and P.B. Raven. Prediction of distress for individuals wearing industrial respirators. Am. Ind. Hyg. Assoc. J. 46:363-368, 1985.

44. Mozo, B.T. and L.J. Peters. Effects of chemical protective and oxygen masks on attenuation and intelligibility when worn with the SPH-4 helmet. Tech. Rpt. 84-5, U.S. Army Aeromedical Research Laboratory, Ft. Rucker, AL, Mar. 1984.

45. Muller, K. The effects of the CBR protective mask on the magnitude of ventilatory or gas-metabolic function while at rest and under working stress. Technical Translation FSTC-HT-23-952-70, U.S. Army Foreign Science and Technology Center, Alexandria, VA, Dec. 1970.

46. Muza, S.R., S. McDonald and F.W. Zechman. Relationship between perceptual performance and load compensation responses to added inspiratory resistance. Fed. Proc. 42: 331, 1983.

47. Muza, S.R. and F.W. Zechman. Scaling of added loads to breathing: Magnitude estimation vs. handgrip matching. J. Appl. Physiol. 57:888-891, 1984.

48. Nelson, W.R. and B.T. Mozo. Effects of XM-40 chemical protective mask on real-ear attenuation and speech intelligibility characteristics of the SPH-4 aviator helmet. Tech. Rpt. 85-2, U.S. Army Aeromedical Research Laboratory, Ft. Rucker, AL, Feb. 1985.

49. Pandolf, K.B. and W.S. Cain. Constant effort during static and dynamic muscular exercise. J. Motor Behavior 6:101-110, 1974.

50. Rauch, T.M., I. Munro, W. Tharion and L.E. Banderet. Subjective symptoms, human endurance and cognitive interventions. Psychology in DOD Symposium. U.S. Air Force Academy, Colorado Springs, Apr. 1986.

51. Raven, P.B., A.T. Dodson and T.O. Davis. The physiological consequences of wearing industrial respirators. A review. Am. Ind. Hyg. Assoc. J. 40:517-534, 1979.

52. Robinson, S. and S.D. Gerking. Heat stress imposed by gas masks. (Report #26). Office of Scientific Research and Development, U.S. War Research Agency, Washington, D.C., 1945.

53. Roussos, C. and P.T. Macklem. The respiratory muscles. New Eng. J. Med. 307:786-796, 1982.

54. Savill, M.W. and M.R. Forrest. The effect of NBC clothing on the noise attenuation of the AFV crewman's helmet. Rpt. No. 11/76, Army Personnel Research Establishment, Farnborough, England, Jun. 1976.

55. Sawka, M.N., R.R. Gonzalez and K.B. Pandolf. Effects of sleep deprivation on thermoregulation during exercise. Am. J. Physiol.: 246:R72-R77, 1984.

56. Sawka, M.N., A.J. Young, R.P. Francesconi, S.R. Muza and K.B. Pandolf. Thermoregulatory and blood responses during exercise at graded hypohydration levels. J. Appl. Physiol. 59:1394-1401, 1985.

57. Silverman, L.G., A.R. Yancey, L. Amory, L.J. Barney and R.C. Lee. Fundamental factors in the design of protective respiratory equipment: A study and an evaluation of inspiratory and expiratory resistances for protective respiratory equipment. (Report #5339). Office of Scientific Research and Development, U. S. War Research Agency, Washington, D.C., 1945.

58. Silverman, L., G. Lee, T. Plotkin, L.A. Sawyers and A.R. Yancey. Air flow measurements on human subjects with and without respiratory resistance at several work rates. Ind. Hyg. Occup. Med. 3:461-478, 1951.

59. Singler, R.T. Early environmental test phase, (Cold Regions Phase) E2G prototype of the XM30 new protective mask, protective hood, and combat spectacles. U.S. Army Cold Regions Test Center Interim Letter Report, May 1981.

60. Snook, S.H., W.C. Hinds and W.A. Burgess. Respirator comfort: subjective response to force applied to the face. Am. Ind. Hyg. Assoc. J. 27:93-97, 1966.

61. Spioch, F.M., R. Kolza and S. Rump. The effects of respirators on some physiological reactions to physical effort. Acta Physiol. Polonica 13:542, 1962.

62. Stemler, F.W. and F.N Craig. Effects of respiratory equipment on endurance in hard work. J. Appl. Physiol. 42:28-32, 1977.

63. Van Huss, W.D., F. Hartman, F.N. Craig and A.H. Steinhaus. Respiratory burden of the field protective mask under exercise load. Fed. Proc. 26:721, 1967.

64. Wiley, R.W., I. Behar, W.C. Chiow and F.F. Holly. Visual and optical analyses of XM-29 and M-24 protective masks. Tech. Rpt. 77-14, U.S. Army Aeromedical Research Laboratory, Ft. Rucker, AL, Jun. 1977.

65. Zechman, F.W. and R.L. Willey. Afferent inputs to breathing: Respiratory sensations. Handbook of Physiology Section 3, The Respiratory System, Vol II Control of Breathing. Ed. N.S. Cherniack and J.G. Widdicombe, Am. Physiol. Soc., 1986.

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